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RESEARCH MEMORANDUM

EVALUATION OF SOME AERODYNAMIC CONTROLS FOR A LOW-ASPECT-RATIO MISSILE

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NATIONAL ADVISORY COMMITTEE
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RESEARCH MEMORANDUM

EVALUATION OF SOME AERODYNAMIC CONTROLS FOR A LOW-ASPECT-RATIO MISSILE*

By Warren Winovich and Nancy S. Higdon

SUMMARY

Results of a static stability controls investigation carried out with a very low-aspect-ratio delta-winged missile are presented. Control effectiveness comparisons are made for tail, canard, and nose control configurations with respect to angle of attack, angle of bank, and Mach number. Trim capabilities of the various configurations are also presented. Theoretical predictions of control effectiveness are made and compared with experimental measurements.

INTRODUCTION

The selection of a particular control for a given missile is frequently a compromise over conflicting requirements. From the control viewpoint, the inherent advantage of the small center-of-pressure travel that is characteristic of delta configurations having low aspect ratio places a premium on control types that preserve or improve this feature.

The purpose of this paper is to discuss the results of a static-stability-controls investigation carried out with the missile configuration shown in figure 1. Besides small center-of-pressure travel with Mach number, the low-aspect-ratio configuration was chosen because of the inherently small induced rolling moment developed during maneuvering conditions. The basic wing-body combination (fig. 1) consists of a 3-caliber ogive nose with a cylindrical afterbody fitted with a cruciform wing. Overall body length is 10 diameters. The cruciform wing has a delta plan form with an aspect ratio of 3/8. Wing panels consist of flat plates with leading and trailing edges beveled. The model was tested with three basic control types (fig. 1): a tail control, a canard control, and a nose control. The center-of-gravity positions to allow a static margin of 0.2 diameter at Mach number 2 resulted in shorter moment arms for the canards; all center-of-gravity stations are in the range of 45 to 55 percent of the body, which represents realistic values.

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SYMBOLS

A	aspect ratio of wing of exposed panels joined together
C_D	drag coefficient based on body area ($\pi d^2/4$)
C_m	pitching-moment coefficient based on body area ($\pi d^2/4$) and body diameter (d)
C_{m_δ}	pitching-moment effectiveness parameter ($\partial C_m/\partial \delta$ evaluated at $\alpha = \delta = 0$)
ΔC_m	incremental pitching-moment coefficient
C_L	lift coefficient based on body reference area ($\pi d^2/4$)
C_Z	normal-force coefficient based on body reference area ($\pi d^2/4$)
d	body diameter
M	free-stream Mach number
$\frac{x}{d}$	center of pressure measured from nose of missile
α	angle of attack
δ	control deflection angle
φ	angle of bank

DISCUSSION

The details of the controls are shown in figure 2. Three types were tested: a diamond-plan-form control with a balanced hinge line; a rectangular control with a balanced hinge line; and a swiveling nose control. The planar types both have wedge-shaped cross sections to reduce center-of-pressure movement on the control. The swivel nose control consists of a forward portion of the ogive nose that pivots in the pitch plane relative to the body axis. The swiveling portion was designed to have the same plan-form area as two of the planar surfaces to make control effects comparable on an area basis.

For the diamond-plan-form cases, the controls were tested interdigitated with respect to the wings as well as inline with the wings. Hence, all four panels were deflected, and the effective control area in the pitch plane was increased by a factor equal to the square root of 2. This factor should be recognized when comparisons are made between inline and interdigitated controls, particularly in the case of control effectiveness.

An assessment of control adequacy depends on prerequisites established by the intended mission. Among the desirable control qualities of an interceptor type of missile is that of possessing stable equilibrium over its operational range with regard to angle of attack as well as Mach number. For simplicity of the guidance system, there should be no control reversal. Further, the missile should be able to fly at trimmed conditions without unduly high trim-drag penalties. Also, control effectiveness should be sufficiently high to allow for development of large normal forces to yield rapid response rates.

The criteria just given are satisfied for a missile that: (1) is able to operate at a small static-stability margin; (2) has no inherent control reversal introduced by configuration nonlinearities; and (3) possesses a control with high effectiveness. This discussion specifies for the given configuration which control type, tail control or canard control, inline or interdigitated, or nose control, has the best qualities.

The effect of the addition of controls to the basic wing-body combination is shown in figure 3. The center of pressure measured from the nose of the missile, x/d, is plotted as a function of angle of attack, α, for 0° control deflection at Mach number 3. The small center-of-pressure travel for the basic wing-body combination was retained at Mach number 5. For comparison, the body-alone center-of-pressure travel is also shown to illustrate the advantage gained by using a low-aspect-ratio wing. Adding canard surfaces in the interdigitated position causes an increase in the center-of-pressure travel at small angles of attack. On the other hand, adding the tail control in the interdigitated position improves the center-of-pressure travel of the basic wing-body combination. For this case, center-of-pressure travel is independent of angle of attack and lies on the centroid of plan-form area. Thus, for the configuration of the present test, addition of control area behind the centroid of area of the basic wing-body combination reduces center-of-pressure travel whereas addition of control area ahead of the centroid of area increases the center-of-pressure travel.

The extremely small center-of-pressure travel shown for the interdigitated tail controls results in linear pitching-moment curves that,

in turn, allow the missile to be trimmed to small values of static margin with no inherent control reversal. On the other hand, the center-of-pressure travel indicated for the canard case results in nonlinearities in the pitching moment at small angles of attack, and therefore yields higher trim penalties.

In figure 4 the control effectiveness at Mach number 2 for the canard and tail controls is shown. The incremental pitching-moment coefficient ΔC_m is plotted against control deflection δ for angles of attack of 0° and 14°. At 0°, as would be expected, the incremental pitching-moment coefficient for the interdigitated cases is greater than that for the inline case by a factor approximately equal to the square root of 2. A comparison of the canard and tail-rearward types shows that the canards are much more effective at small control deflections. This indicates that, for this specific canard configuration where the control span is the same as the wing span, unexpected favorable interference occurs. When operating at combined angle of attack and control deflection at this Mach number, the canard configurations show a reduction of control effectiveness which is of the order of 50 percent at an angle of attack of 14° and large control deflection. This is caused by the stalling of the canard surfaces which are deflected positively to trim. For the interdigitated tail control, however, there is essentially no change in control effectiveness at combined angle of attack and control deflection. The inline tail controls exhibit a constant control-effectiveness reduction of about 15 percent at combined angle of attack and control deflection owing to their location in the wake of the wing. Therefore, the interdigitated tail realizes a gain in control effectiveness which is greater than the square-root-of-2 factor.

Comparison of figures 4 and 5 shows the effect of Mach number on control effectiveness for the canard and tail controls. The arrangement of the two figures is the same. At 0° angle of attack, the incremental pitching-moment coefficient is decreased by the inverse ratio of β $(= \sqrt{M^2 - 1})$ in accordance with linear theory. This holds for all of the planar control types tested. At combined control deflection and angle of attack at Mach number 3 (fig. 5), the interdigitated canard control exhibits favorable interference, just the opposite of the effect found at Mach number 2 (fig. 4). The interdigitated tail control, however, shows a negligible effect of angle of attack at both Mach numbers.

The rectangular-plan-form tail control develops the same control effectiveness at small angles of attack as does the diamond-plan-form control. At combined angle of attack and control deflection the rectangular-plan-form control with one-quarter-chord gap retains control effectiveness. The effect of decreasing the gap from one-quarter chord to zero was to linearize the pitching moment. The linearizing effect of the zero-gap rectangular-plan-form tail control can be attributed to

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viscous effects which prevent the flow from passing through the wing-control gap as the control unports initially. The more linear variation of pitching-moment coefficient resulted in slightly higher trim normal-force coefficients than were obtained for both the inline diamond configuration and the one-quarter-chord gap rectangular tail configuration.

For the swivel nose control it was found that control effectiveness increased slightly between Mach numbers 2 and 3. An analysis in which control effectiveness was calculated, assuming that the swiveling ogive can be replaced by a cone, predicts such an increase. However, the effectiveness of the nose control is low; for example, at Mach number 3 it is less than half the value corresponding to the interdigitated tail control.

The effect of bank angle on pitching-moment effectiveness is shown in figure 6. For the case shown, the missile receives a command to maneuver toward a target that is at an angle ϕ relative to the missile. The maneuver is accomplished by deflecting all four control panels to go directly to the target without rolling. The control effectiveness C_{m_δ} shown on the ordinate is developed in the plane of the target. The dashed lines represent linear theory with no regard for interference effects. The points are results of wind-tunnel tests at Mach number 3 and an angle of attack of 12°.

The theory indicates no advantage for either type of control owing to symmetry at $\varphi = 45^\circ$. However, at 45° the inline configuration does not realize the theoretical prediction because of the location of the control panels in the wakes of the wings. The interdigitated control, which is positioned more favorably, has no wake interference effects and develops practically as much pitching effectiveness as the inline control at 45°. Thus, the interdigitated control has a slight advantage in this maneuver over a wider angle range.

For the long-chord low-aspect-ratio configuration at combined angles of attack and sideslip, tests at the Langley Aeronautical Laboratory and the Ames Aeronautical Laboratory have shown that there is adequate roll control up to Mach number 6.

In figure 7, the trim capabilities of the control types are compared. In this figure trim normal-force coefficient $C_{N_{TRIM}}$ is plotted as a function of the trim control deflection δ_{TRIM} at Mach number 3. All types were trimmed to the same static margin to make this comparison. Owing to the excellent center-of-pressure characteristics the interdigitated tail control develops the highest normal force for a given control deflection. Although the interdigitated canard showed the largest center-of-pressure travel, the favorable interference that was observed to exist enables this control type to develop high normal forces also. The lowest curve

represents the swivel-nose-control case as well as the inline diamond and rectangular tail and canard controls. As shown, the maximum trim normal-force coefficient for this group is only slightly greater than 2. By resorting to interdigitation of the control panels it is possible, therefore, to develop over twice the trim normal force relative to the inline types.

The trim lift-drag polars are shown in figure 8. The trim lift coefficient is shown as a function of the trim drag coefficient at Mach number 3 for the various configurations. The dashed line represents the untrimmed case which is essentially the same for all control types. The minimum drag for the canard types is slightly higher than that for the tail-rearward types. For any given lift coefficient the plot shows that the drag penalty is least for the interdigitated tail control.

In figure 9 the comparison is made of the agreement between experimental and predicted control effectiveness as a function of Mach number. The dashed curve is the linear theory result of reference 2 which takes into account panel-body interference. The circles represent experimental data for the interdigitated tail control. Theory overpredicts control effectiveness by an almost constant percentage. The trend predicted by linear theory of the falloff of effectiveness with Mach number holds for Mach numbers up to 6. Although the control effectiveness decreases with Mach number, the good moment characteristics of the interdigitated tail control at combined control deflection and angle of attack still allow large trim forces to be developed at the higher Mach numbers.

In figure 10 the same comparison is shown for the interdigitated canard control. For this case, theory underpredicts the experimental values. This occurs over the entire Mach number range and illustrates that favorable interference acts to increase the control effectiveness at 0° angle of attack for this particular canard surface. However, at combined control deflection and angle of attack it has been noted that the interference can be unfavorable. The decrease of control effectiveness with Mach number is again closely predicted by linear theory.

CONCLUDING REMARKS

For the delta configuration having low aspect ratio tested in this investigation, the interdigitated tail control comes closest to satisfying the criteria given. This control actually improves the stability of the basic wing-body combination. Small center-of-pressure travel allows trimming at small stability margin with subsequent small trim-drag penalties. Larger trim normal forces can be developed for this control than can be developed for inline-control types. Finally, the favorable location

of the control panels away from the wing wake minimizes interference effects so that the control effectiveness is maintained over wide limits.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., Mar. 19, 1958

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2. Pitts, William C., Nielsen, Jack N., and Kaattari, George E.: Lift and Center of Pressure of Wing-Body-Tail Combinations at Subsonic, Transonic, and Supersonic Speeds. NACA Rep. 1307, 1957.

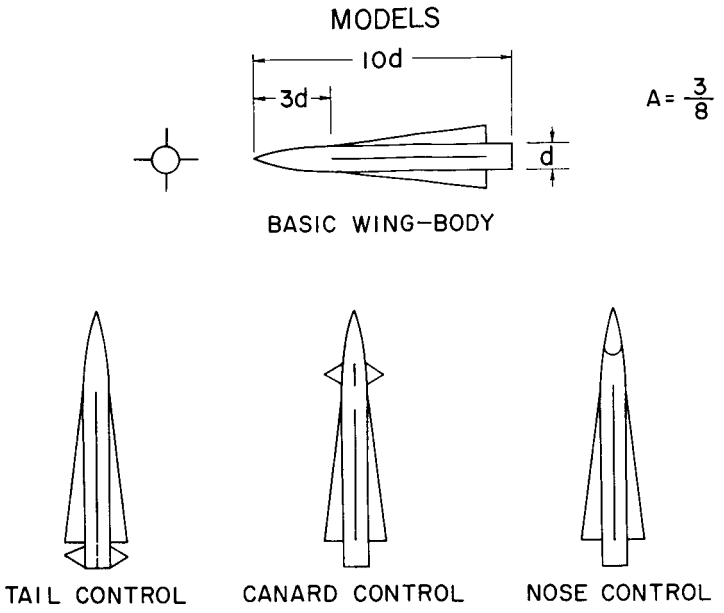


Figure 1

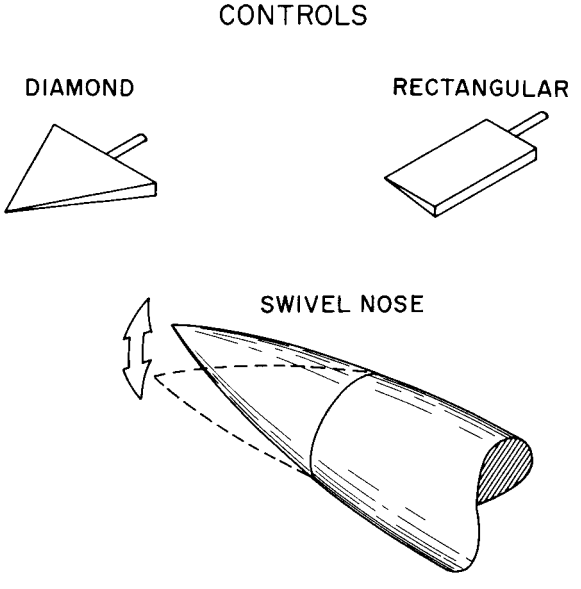


Figure 2

EFFECT OF CONTROL ON CENTER OF PRESSURE

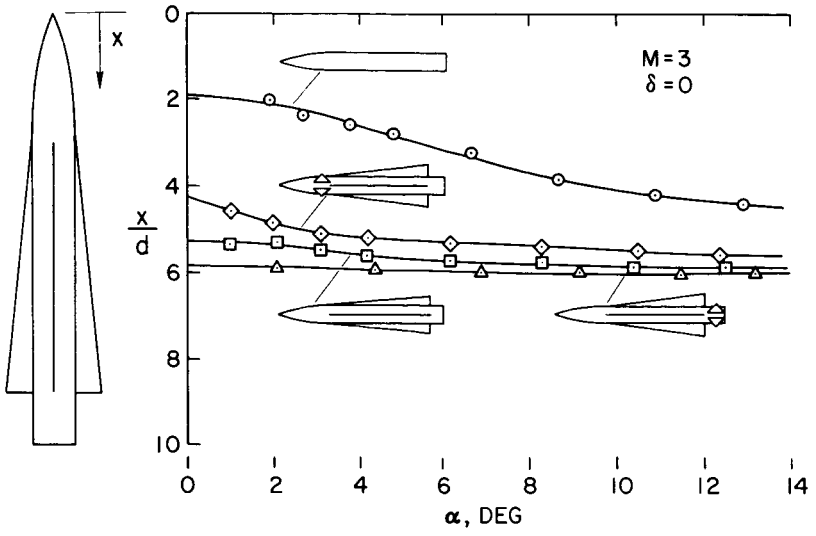


Figure 3

CONTROL EFFECTIVENESS

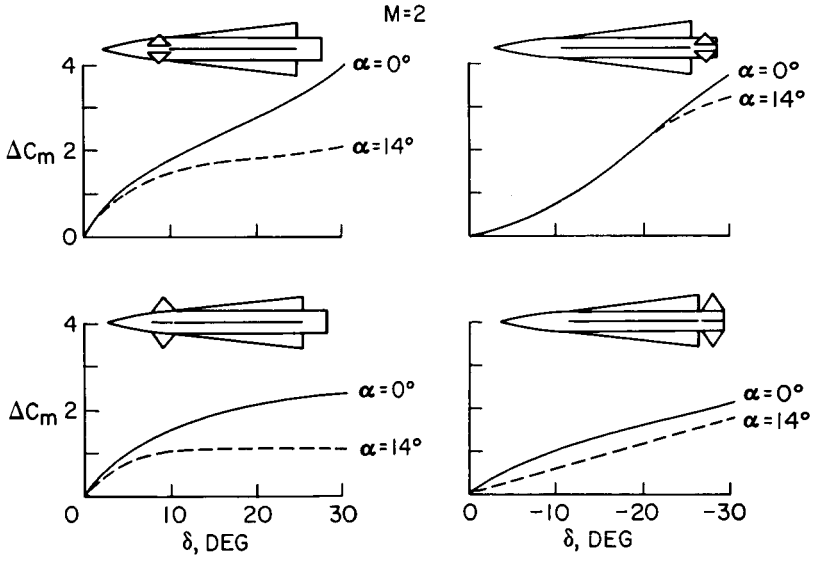
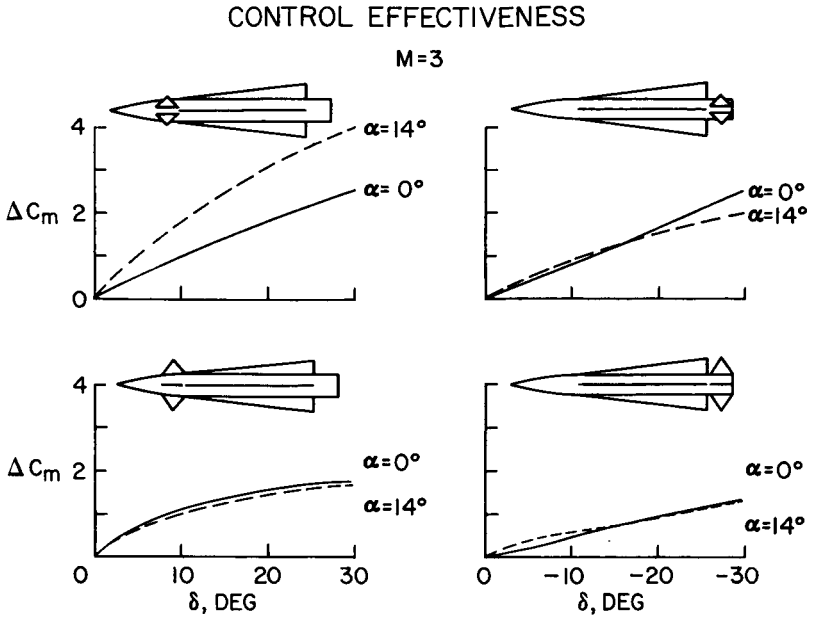


Figure 4



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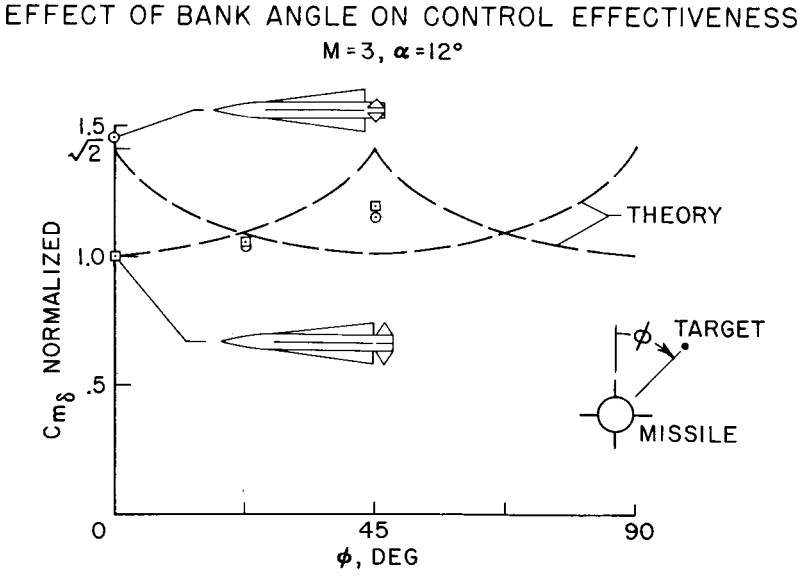

Figure 6

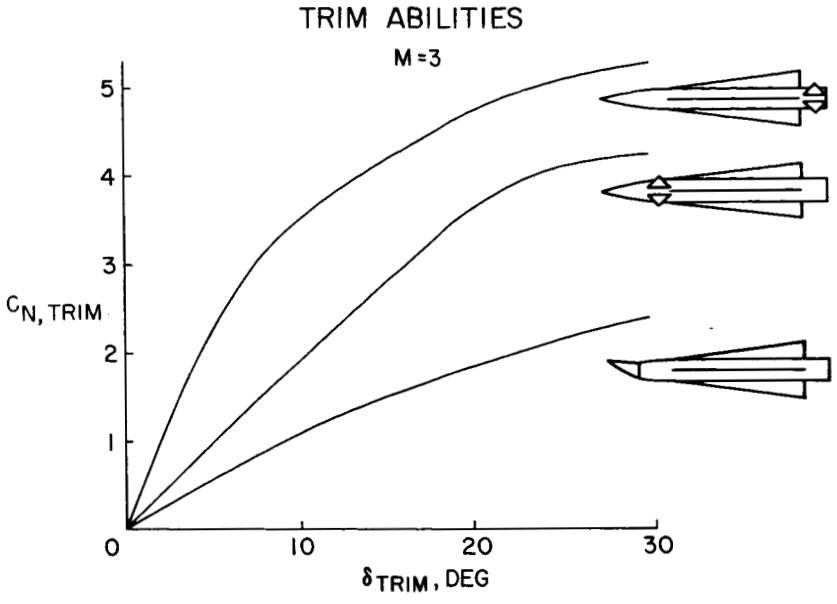

Figure 7

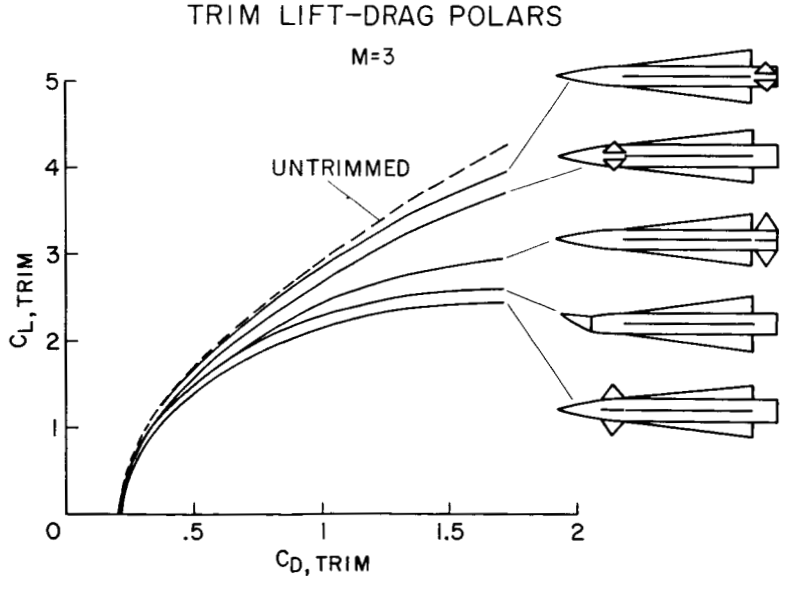

Figure 8

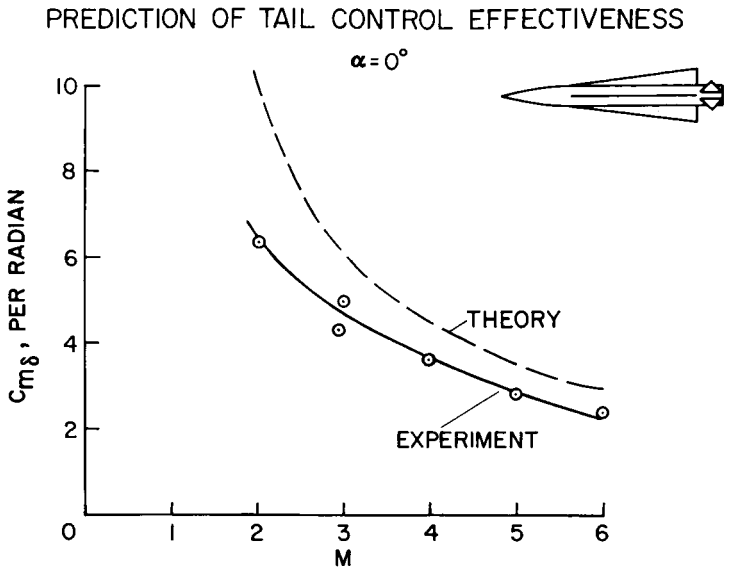

Figure 9

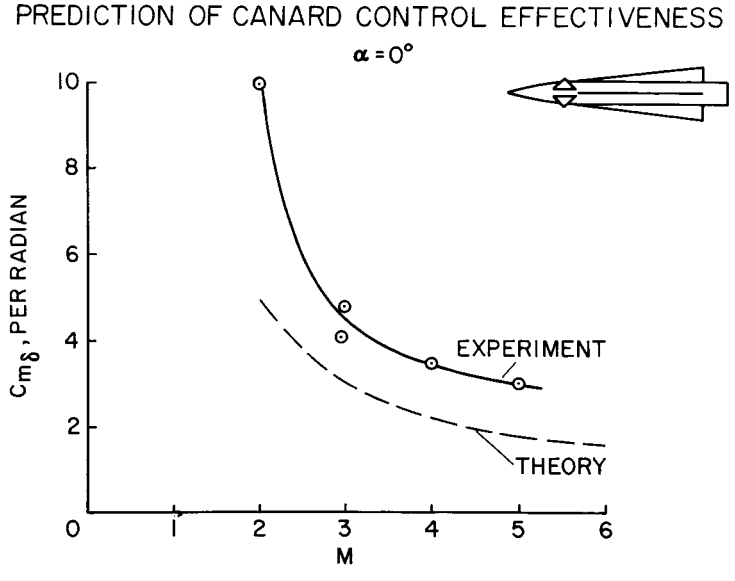

Figure 10

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